

EFFECT OF PROJECT DESIGN QUALITY ON THE PERFORMANCE OF ENERGY PROJECTS: A CASE OF THE ENERGY ACCESS AND QUALITY IMPROVEMENT PROJECT IN RUBAVU AS WELL AS MUSANZE DISTRICTS, RWANDA (2022–2025)

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Abstract: This study, entitled “Effect of Project Design Quality on the Performance of Energy Projects: Case of EAQIP, Rwanda,” aims to assess how project design quality influences the performance of energy projects implemented under the Energy Access and Quality Improvement Project (EAQIP) in Rwanda. The study is motivated by the need to improve energy service delivery in terms of access, reliability, cost-effectiveness, environmental sustainability, and socio-economic development, despite ongoing investments in the energy sector. It specifically examines how tools for energy project design, human resources, stakeholder engagement, resource optimization, and infrastructure grid and off-grid integration contribute to energy project performance outcomes. The study was guided by a descriptive and correlational research design and adopted a mixed quantitative approach. The target population consisted of 126 EAQIP stakeholders, including project managers, engineers, government officials, environmental specialists, and community representatives involved in project design and implementation. A total of 118 respondents participated in the study, representing a 93.7% response rate, which was considered sufficient for reliable statistical analysis. Data was collected using structured questionnaires and supplemented by selected stakeholder insights to enrich understanding of project design practices. The data were analyzed using descriptive statistics, Pearson correlation, and multiple regression analysis to determine relationships between variables and test hypotheses. Findings revealed that all dimensions of project design quality positively and significantly influence energy project performance. Resource optimization and efficiency emerged as the strongest predictor of performance, followed by infrastructure grid and off-grid integration, stakeholder engagement, tools for project design, and human resources. Results further showed that project design quality explained 51.1% of the variation in energy project performance ($R^2 = 0.511$, $p < 0.001$), confirming a strong and statistically significant relationship between the variables. The study concludes that project design quality is a key determinant of energy project performance in Rwanda. It recommends strengthening resource optimization practices, enhancing the use of advanced design tools, improving human resource capacity, and promoting integrated grid and off-grid systems alongside inclusive stakeholder participation to improve energy sector outcomes.

Keywords: Project Design Quality, Energy Project Performance, Energy Access, Stakeholder Engagement, Resource Optimization.

0. Introduction

Project Design Quality has an important interest in energy project success, particularly in developing countries, as inefficient energy projects, with high operational costs, and projects that do not meet their intended objectives, can negatively impact energy access, quality, and cost-effectiveness (Zhao, 2020). Project Design Quality, such as identifying local needs, engaging with stakeholders, and

selecting appropriate technologies, can help ensure that energy solutions are sustainable and will ultimately achieve the national and regional energy access goals (Martínez, 2020).

Across parts of Asia, thoughtfully planned energy systems matter more each year - India shows this clearly. Its national push for solar power grows stronger because layout choices support both wider access and lower pollution levels. Instead of rushing forward blindly, Chinese efforts tie strong planning to fast growth in wind and sunlight-based electricity networks. Because attention sticks to structure and function, China now produces more renewable energy than most nations. After Fukushima changed expectations in 2011, Japan reshaped how it builds power systems - safety shapes every choice now. Careful thinking guides upgrades meant to last, balancing long-term risks alongside daily needs. Thought enters early, stays late, when systems must endure stress and time alike.

Smart grids plus efforts to save power reshaped how America handles electricity. Brazil's shift toward plant-based fuels lessened its need for oil while strengthening supply safety. Thoughtful rules and steady policies pushed Mexico toward sun and wind power. Clear planning helped make these changes stick across nations. Each step forward came from matching goals with real actions on the ground.

Across Europe, nations like Germany, Denmark, and the UK moved early on clean energy efforts. What stands out is how Germany shaped its shift to renewables through Energiewende - proof that thoughtful structure matters (Sperling, 2017). Wind power took root in Denmark thanks to consistent policy moves paired with smart system layout (Thomsen et al., 2018). Meanwhile, offshore wind growth in the UK followed clear blueprints, helping lower pollution levels over time (Harrison, 2020).

It's clear across Africa that solid energy project designs matter deeply. Because many nations deal with weak infrastructure, spotty power networks, and fast-rising numbers of people, thoughtful planning becomes essential. Take South Africa - its REIPPPP program shows how smart structure draws funding while boosting clean power sources (Mavhungu, 2021). Elsewhere, Kenya poured resources into geothermal systems, proving precise early stage thinking helps deliver dependable, long-term electricity (Rono, 2019). Then there's Morocco: the Noor Ouarzazate Solar Complex highlights what happens when vision shapes big renewable efforts - energy safety gets stronger nationally (Nouredine, 2020).

East Africa must get energy projects right, simply because millions still live without reliable power. Ethiopia, Tanzania, and Uganda struggle with deep gaps in electricity availability - this drives their push for smarter solutions. Instead of copying old models, they explore fresh approaches that fit local realities better. Take Ethiopia: its massive dam project aims to reshape how the nation produces electricity (Abdulahi, 2019). Meanwhile, sunlight and rivers become key tools in Tanzania's and Uganda's plans, rolled out through structured efforts to reach more people (Abdulahi, 2019).

Though cut off from the sea, Rwanda supports more than 13 million residents while steadily upgrading how it delivers power. Energy reach and reliability sit high on the national agenda, backed by structured efforts like EAQIP. Driven by long-term goals, this initiative fits with wider plans to bring steady electricity across towns and countryside alike. Thoughtful layout and forward-looking blueprints shape EAQIP's path, targeting not just wider service but lasting performance in every region (REG, 2020).

The EAQIP is also a critical component of the Rwanda development agenda that is reflected in the Vision 2050 and the SDGs, and its goal is to expand the national grid and invest in off-grid renewable energy sources to ensure that the energy reaches every part of the country. The EAQIP focuses on both expanding the physical infrastructure and improving the management of energy resources to create a reliable, sustainable, and universal energy system, building on the lessons from previous energy projects in Rwanda and around the world (REG, 2020). Therefore, this assesses the Effect of Project Design Quality on Energy Projects: A Case Study of the EAQIP in Rwanda.

1. Problem Statement

Despite global efforts to expand sustainable energy access, energy projects in developing countries continue to experience delays, cost overruns, unreliable services, and operational inefficiencies, often due to weaknesses in project design, resource utilization, stakeholder participation, and integration of grid and off-grid technologies (Mensah, 2020; IRENA, 2022; Mavhungu, 2021; Zhang, 2021). Globally, approximately 675 million people lacked access to electricity in 2021, with nearly 80% living in Sub-Saharan Africa, demonstrating persistent challenges in energy infrastructure development (IEA, 2023; World Bank, 2022). Rwanda has made substantial progress in electricity access, increasing national electrification from approximately 34% in 2017 to over 70% in 2023, partly through the EAQIP and other national electrification programmes (REG, 2023; World Bank, 2022).

However, challenges remain, particularly in rural areas, where inadequate project design, inefficient resource use, limited stakeholder engagement, and weak integration of grid and off-grid systems can affect energy access, reliability, affordability, environmental sustainability, and socio-economic development (IEA, 2023; IRENA, 2022; Cardoso, 2021). If these challenges persist, unreliable energy supply may continue to constrain business productivity, economic growth, healthcare, education, and social welfare (World Bank, 2022; United Nations, 2023). Therefore, improving Project Design Quality, particularly through effective design tools, skilled human resources, stakeholder engagement, resource optimization, and grid/off-grid integration, is essential for improving energy project outcomes and supporting SDG 7 on affordable, reliable, sustainable, and modern energy for all (United Nations, 2023). This study therefore investigates the effect of Project Design Quality on the performance of energy projects under EAQIP in Rubavu and Musanze Districts, Rwanda, during 2022–2025.

2. Empirical Review

By Zhang et al. (2021), the researchers aimed to investigate how the use of various tools for energy project design quality, such as simulation software and risk management frameworks, influenced the performance of renewable energy projects. The methodology employed was a mixed strategy, integrating interviews with project managers and quantitative evaluation of project performance indicators. The research revealed that tools such as energy modeling and cost-benefit analysis significantly improved the accuracy of project forecasting, leading to better resource allocation and reduced project delays. However, the study's gap lies in its focus on renewable energy projects alone, leaving the broader spectrum of energy projects, including those for rural electrification, less explored. This gap is addressed by the current study, which includes energy access projects like the EAQIP in Rwanda (Zhang et al., 2021).

A similar study by Roberts and King (2022) examined the role of energy project design quality tools in optimizing the performance of microgrid projects in developing countries. The authors used a case study methodology, focusing on two microgrid installations in rural Africa. The results suggested that design tools that incorporate local knowledge and stakeholder participation resulted in higher energy reliability and social acceptance. The limitation of the study is that it did not consider the long-term operational phase of the projects. This gap will be filled by the current study, which takes a more comprehensive look at the entire life cycle of energy projects, from design to operation (Roberts & King, 2022).

Miller and Santos (2020) examined how energy modeling software influences the outcomes of grid expansion initiatives in Latin America. Using a quantitative survey method, they assessed improvements in cost, time efficiency, and energy output after implementing these tools. Their findings indicated that advanced design technologies contributed to greater cost-effectiveness and fewer operational interruptions. However, the research did not account for region-specific conditions, especially those relevant to Sub-Saharan Africa. The present study responds to this limitation by focusing on the distinct challenges related to expanding energy access and improving service quality in Rwanda (Miller & Santos, 2020).

Nixon et al. (2021) explored the role of geospatial tools in enhancing the design quality of off-grid energy projects. Through a case study approach, they evaluated off-grid solar initiatives in East Africa and discovered that geographic information systems (GIS) helped more accurately identify underserved areas, thereby improving project reach and long-term viability. A key constraint of their work was its exclusive focus on off-grid systems, leaving out broader energy infrastructure developments. To address this, the current research expands the scope by incorporating both off-grid and grid-connected projects within the framework of the EAQIP (Nixon et al., 2021).

Lastly, Davis et al. (2022) explored the role of software tools for energy demand forecasting and their effect on the performance of urban energy systems. The authors employed a qualitative method, interviewing urban planners and energy analysts, and found that proper demand forecasting improved the operational efficiency of energy projects. However, the study did not consider rural or remote energy projects, which have different design and performance challenges. The current study addresses this by focusing on a rural energy access project in Rwanda (Davis et al., 2022).

Lee and Kim (2021) conducted a quantitative survey of 120 project managers in the energy sector and found that skilled human resources during the design phase have a positive correlation with project success (timely completion and budgetary goals). The current study fills this gap by focusing on the human resource aspects in the context of energy access projects (Lee & Kim, 2021).

Likewise, Gao et al. (2022) investigated the impact of training and capacity building on energy project performance, with a focus on projects in Sub-Saharan Africa, using a qualitative approach based on interviews with stakeholders from energy projects in Kenya and Uganda. Although the researchers found that continuous training of local workers and project managers improved project outcomes, especially in terms of energy reliability and community acceptance, their study did not investigate the relationship between human resources and long-term project sustainability, which is addressed in the current study through an examination of short-term and long-term performance indicators (Gao et al., 2022).

For example, in a mixed-methods comparative study, Park and Jang (2023) examined how local versus expatriate labor affected the success of energy projects in developing countries. The findings showed that projects that were led by local teams performed better in terms of social and economic development because local workers had a better understanding of the needs of the community, but the integration of human resources into the design phase was not included in the study. The gap could be handled by exploring how human resources are used throughout the design phase (Park & Jang, 2023).

Previous research on human resource management and energy project performance in large-scale renewable energy projects focused on the role of project management teams and clearly defined roles (Harris et al., 2021), but not on local human resources, which can be key to local human resources in rural electrification projects. The gap is filled by assessing the influence of local human resources on energy access projects in Rwanda (Harris et al., 2021).

Another study by Lee et al. (2022) analysed how human capital contributes to the design and implementation of energy projects and concluded that human resources with higher technical skills had a positive impact on the performance of energy projects in terms of quality and operational efficiency, but they focused on large-scale projects and did not include small- and medium-sized projects such as those in rural areas. The current study overcomes this by focusing on a particular rural energy project in Rwanda (Lee et al., 2022).

A study by Smith and Jones (2020) examined how stakeholder engagement influenced the performance of energy projects, specifically in the context of solar power installations in rural Africa. They used a case study methodology and stakeholder involvement in the planning and design phases had greater community acceptance and better long-term outcomes. The study's gap was its limited focus on one type of energy project, and the current research addresses this by exploring a broader range of energy project types, including off-grid and grid-connected projects in Rwanda (Smith & Jones, 2020).

Another study conducted by White and Patel (2021), which used a mixed methods design to incorporate interviews with stakeholders and survey of project outcomes, found that energy projects that engaged local communities in decision-making had better energy reliability and efficiency, although the economic and social impacts of stakeholder engagement were not considered. This study extends this by including social and economic considerations of stakeholder participation (White & Patel, 2021).

A study by Thompson et al. (2022) investigated how early engagement with stakeholders influenced the design and performance of wind energy projects in Southern Africa. They found that early stakeholder consultations reduced opposition to projects and led to faster approvals. However, the study did not consider the long-term operational phase of projects. The current study fills this gap by including both the design and operational phases of energy projects (Thompson et al., 2022).

In a different context, Lee et al. (2021) examined stakeholder engagement in energy projects in the Middle East and found that the involvement of government agencies and NGOs improved project outcomes in terms of funding and regulatory support. However, the study did not explore community-level participation, which is crucial for energy access projects in rural areas. The current study addresses this by focusing on local stakeholder participation in the context of the EAQIP in Rwanda (Lee et al., 2021).

Finally, Clark and Johnson (2023) examined the impact of stakeholder engagement practices on the performance of hydropower projects in Africa, using a case study approach to demonstrate that projects with high levels of stakeholder involvement had better environmental sustainability and social outcomes; this study did not specifically consider the influence of local stakeholders in the design phase, which is addressed in this study focusing on stakeholder participation in the design and implementation of energy access projects (Clark & Johnson, 2023).

One look at Johnson et al. (2022) shows how managing resources shapes energy project results. Better handling of workers and supplies tied directly to tighter budgets, less waiting time, faster output. Their method leaned on real-world examples across Sub-Saharan Africa, zeroing in on big clean power efforts. Yet those smaller setups - especially off-grid village systems - were left out. That blank spot? This work steps into it. With Rwanda's EAQIP as the lens, the picture now includes what earlier missed pieces. Johnson's team opened the door; this study walks through.

One case comes from Carter and James in 2021 - they investigated material choices and worker planning, seeing how these shaped cost and long-term power output in water-based energy efforts. Yet community growth stayed outside their view when it came to managing supplies wisely. This work steps in by weighing money factors alongside people's outcomes in using resources well - building on what those researchers started. Then there is Brown with Moore three years later: they checked solar builds where smarter supply use meant hitting deadlines plus staying on spending limits. Finishing strong like that led to steadier electricity flow for more households. Other kinds of energy plants? Those never entered the picture.

Elsewhere, Brown and Moore looked at how well resources were used in solar power efforts compared to deadlines. When materials, people, and funds were handled wisely, work finished as planned without overspending - this helped more households gain steady electricity. Still, their research focused only on sunlight-based setups, ignoring wind, hydro, or fossil alternatives. To go further, this analysis includes various energy forms, reaching into connected grids along with isolated units running outside main networks.

Another relevant study by Lee et al. (2020) analyzed resource optimization in wind energy projects. They found that projects that employed advanced data analytics to predict resource needs performed better in terms of cost-effectiveness and sustainability. However, the study was based on developed economies and did not account for resource constraints in developing countries. The current study addresses this by focusing on resource optimization in the context of energy access projects in Rwanda (Lee et al., 2020).

Lastly, a study by Nguyen and Tran (2022) investigated efficiency of rural electrification projects. They found that optimizing resources, including human capital and materials, led to more effective energy distribution and enhanced operational efficiency. However, the study did not cover the impact of resource management on environmental sustainability, which the current study includes as part of its assessment (Nguyen & Tran, 2022).

One look at work led by Kim and team in 2021 shows how mixing power grids with standalone setups shapes Energy Project results. Success often came when both types linked well, making supply steadier, especially far from city centers. Instead of isolated case reviews, they compared projects across Sub-Saharan Africa using side-by-side methods. Yet what slipped through was daily trouble in running these mixed-energy models. Now comes fresh attention: Rwanda's efforts bring those hidden hurdles into view. Earlier findings set the stage, but real-world friction stays uncharted.

Parker and Thompson investigated mixing regular power grids with standalone setups back in 2022. Their work showed these combined models reached more people, especially in remote villages, while cutting down uneven access to electricity - yet they left out any look at environmental effects. This research steps in right there, turning attention toward how such blends affect both nature and communities. Evidence from a real-world example in Southeast Asia revealed better energy reach alongside smarter use of wind and solar when systems merged - Smith's team reported that finding three years ago. Any clear picture on whether those joined networks could stay financially strong over time. That piece gets explored here, zeroing in on how linked energy solutions shape ecosystems and economies alike.

One project looked at mixing connected and standalone power setups across Southeast Asia. It found better access to electricity through combining both types of networks. Efficiency with green energy went up because of this blend. Yet there was no look into whether these combined systems could stay funded over time. This work now turns toward money matters in those mixed-energy efforts. Long-term survival depends on financial health, which earlier missed attention. One look at Africa's power setups shows what happens when separate solar networks meet main electricity lines. Zhang and Lee investigated this mix in 2023, spotting clearer gains in price

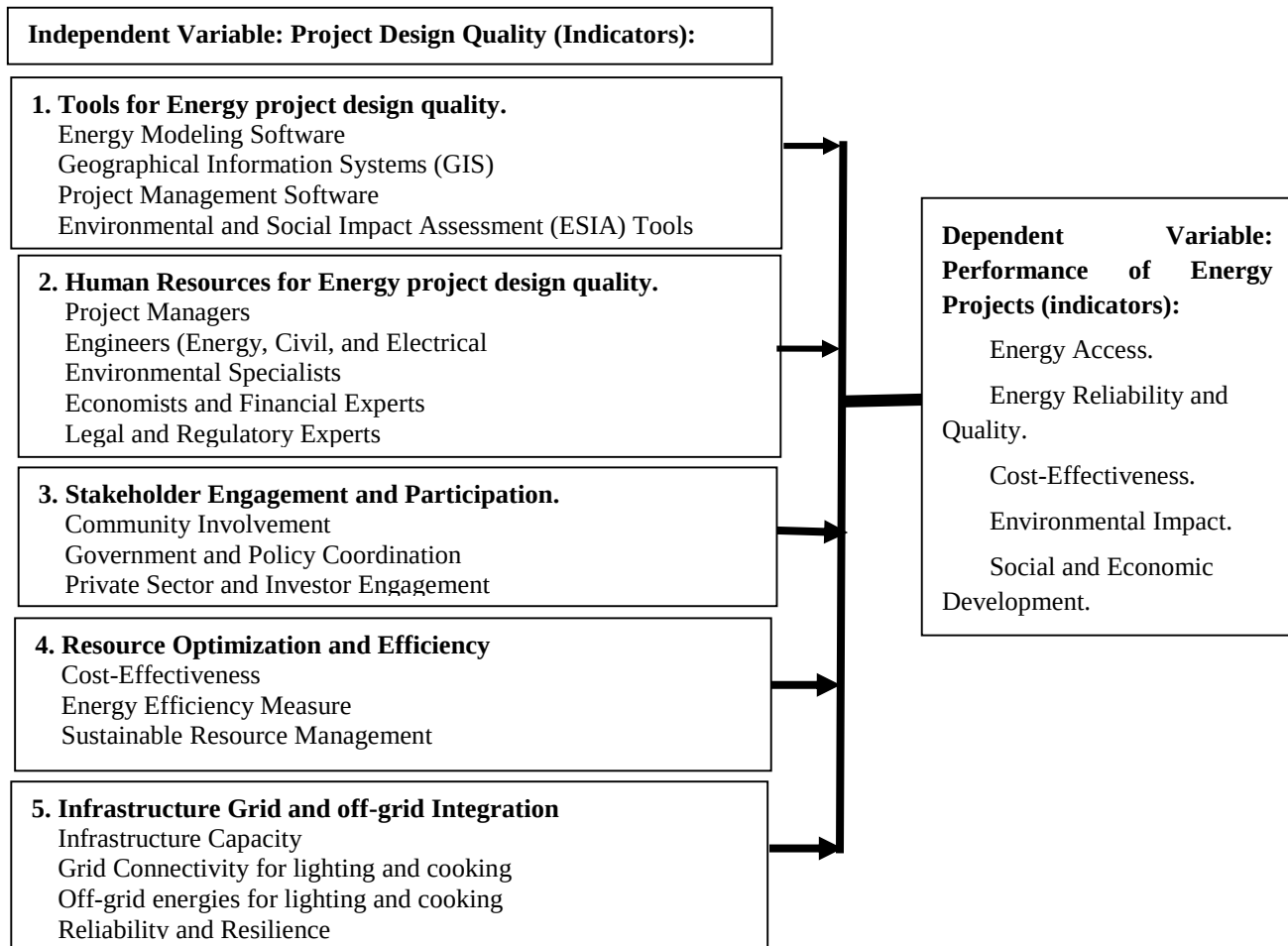
efficiency and steady supply. Yet their work missed deeper questions about people - like whether locals had really said during changes. That missing piece? It moves front and center here, where voices shaping these transitions get attention too. What came before sets the stage, now participation steps into view.

Ending things off, Wang and colleagues looked at how renewable energy connects to power networks in remote parts of China. Projects combining connected and standalone setups held up better over time, hitting goals more reliably. Still missing was an examination of ecological effects from blending these systems - something this work takes on, zeroing in on efforts to expand electricity access in Rwanda (Wang et al., 2022).

3. Conceptual framework of the study

The indicators associated with the independent variable Project Design Quality are more closely associated with energy project performance due to factors related to project design, human resources, stakeholder engagement, resource optimization, and infrastructure integration. For example, strong tools for project design quality lead to projects that are designed for efficient execution and scalability, which are direct determinants of energy project performance (energy access, reliability), and common pitfalls (underperformance, delays, cost overruns) are avoided, which can derail key performance indicators (KPIs) such as energy access and reliability (Johnson et al., 2022).

Figure 1: Conceptual Framework of the Study



Source: Author, (2026)

4. Study Methodology

This section gives in details methods and techniques which are used to achieve study objectives and testing validity of the study objectives and hypotheses. It shows study design, population and sample size, sampling techniques, data collection tools, methods for data processing and data analysis. Here below are details:

4.1 Study objective

To assess the level of Project Design Quality in energy projects under EAQIP in Rubavu and Musanze Districts, Rwanda, in terms of design tools, human resources, stakeholder engagement and participation, resource optimization and efficiency, and grid and off-grid infrastructure integration.

To assess the performance of energy projects under EAQIP in Rubavu and Musanze Districts, Rwanda, in terms of energy access, energy reliability and quality, cost-effectiveness, environmental impact, and social and economic development.

To determine the relationship between Project Design Quality and the performance of energy projects under EAQIP in Rubavu and Musanze Districts, Rwanda.

4.2 Study Hypotheses

The current study relays on the following hypothesis, such as:

Null Hypothesis (H_0): There is no significant relationship between Project Design Quality and the Performance of Energy Projects under the Energy Access and Quality Improvement Project (EAQIP) in Rubavu and Musanze Districts, Rwanda.

Alternative Hypothesis (H_1): There is a significant relationship between Project Design Quality and the Performance of Energy Projects under the Energy Access and Quality Improvement Project (EAQIP) in Rubavu and Musanze Districts, Rwanda.

4.3 Summary of Methodology

The study employed mixed-methods, descriptive, and correlational research design to examine the effect of Project Design Quality on the performance of energy projects under the Energy Access and Quality Improvement Project (EAQIP) in Rubavu and Musanze Districts. A census approach was adopted, whereby all 126 stakeholders involved in the project, including project managers, engineers, design teams, field team leaders, and district energy staff, were included in the study. This approach ensured comprehensive coverage of the target population and minimized sampling bias. The study combined quantitative and qualitative methods to obtain both measurable data and detailed stakeholder insights regarding project design quality and project performance.

Data was collected from both primary and secondary sources. Primary data were obtained through structured questionnaires, interviews, and focus group discussions, while secondary data were gathered through documentary reviews of project reports, policy documents, books, journals, and other relevant publications. Structured questionnaires containing Likert-scale and open-ended questions were administered to EAQIP stakeholders, while interviews and focus group discussions provided deeper insights into project design practices, implementation experiences, and performance outcomes. The use of multiple data collection instruments enhanced data triangulation and strengthened the credibility of the findings.

To ensure quality, the research instruments were subjected to validity and reliability testing. Content, construct, and criterion-related validity were established through expert reviews, pilot testing, and alignment with existing literature. The Content Validity Index (CVI) exceeded the acceptable threshold of 0.70. Reliability was assessed through a pilot study involving 13 participants and measured using Cronbach's Alpha coefficients. All study variables recorded reliability values above 0.70, with an overall reliability coefficient of 0.914, demonstrating excellent internal consistency of the research instrument.

Data processing involved editing, coding, classification, and tabulation of responses before analysis. Quantitative data were analyzed using SPSS through descriptive statistics, including frequencies, percentages, means, and standard deviations. Inferential statistics, specifically Pearson correlation and multiple linear regression, were employed to determine the relationships and predictive effects of project design quality dimensions on energy project performance. Qualitative data from interviews, focus group discussions, and open-ended responses were analyzed thematically and used to complement and explain the quantitative findings. Ethical principles including informed consent, confidentiality, voluntary participation, and responsible use of data were observed throughout the study.

5. Findings

5.1 Project Design Quality Best Practices Ensured by EAQIP Stakeholders

This section presents respondents' perceptions regarding the project design quality best practices implemented under the Energy Access and Quality Improvement Project (EAQIP). The analysis focuses on the five key dimensions of project design quality, namely tools for energy project design quality, human resources, stakeholder engagement and participation, resource optimization and efficiency, and infrastructure grid and off-grid integration. The purpose is to assess the extent to which these practices have been adopted and their contribution to the successful implementation and performance of energy projects. The findings provide an overview of the strengths of EAQIP's project design approach and establish a foundation for examining the relationship between project design quality and energy project performance.

Table 1: Summary of Project Design Quality Best Practices under EAQIP (n = 118)

Project Design Quality Dimension	Key Finding	Percentage (%)	Rank
Human Resource Expertise	Most emphasized project design best practice	27.1	1
Stakeholder Engagement and Participation	Important design best practice	23.7	2
Tools and Technology Integration	Significant design practice	20.3	3
Resource Optimization and Efficiency	Moderately emphasized design practice	16.1	4
Infrastructure Grid and Off-Grid Integration	Least emphasized but important design practice	12.8	5
Qualified Technical Staff	Most important contributor to successful project implementation	29.7	1
Strong Stakeholder Coordination	Second most important contributor to implementation success	24.6	2

Project Design Quality Dimension	Key Finding	Percentage (%)	Rank
Infrastructure Strengthening	Important implementation contributor	18.6	3
Energy Modeling and GIS Tools	Supports project implementation effectiveness	15.3	4
Efficient Resource Management	Contributes to implementation success	11.8	5
Donors and Development Partners	Active stakeholder involvement	100	1
Engineers	Active stakeholder involvement	96.6	2
Project Managers	Active stakeholder involvement	94.9	3
Government Agencies	Active stakeholder involvement	89	4
Environmental Specialists	Active stakeholder involvement	82.2	5
Local Community Representatives	Active stakeholder involvement	79.7	6
Legal and Regulatory Experts	Active stakeholder involvement	74.6	7
Private Sector Investors	Active stakeholder involvement	61	8

Overall Mean Scores of Project Design Quality Dimensions

Dimension	Overall Mean	Interpretation	Rank
Infrastructure Grid and Off-Grid Integration	4.4	Strong	1
Human Resources for Project Design Quality	4.28	Strong	2
Resource Optimization and Efficiency	4.22	Strong	3
Stakeholder Engagement and Participation	4.28	Strong	2
Tools for Energy Project Design Quality	4.27	Strong	4

Source: Source; Field Data, 2026

Table 1 findings indicate that EAQIP has successfully integrated all major dimensions of Project Design Quality, with all dimensions recording mean scores above 4.0, which reflects a strong level of agreement among respondents. Human resource expertise emerged as the most emphasized project design best practice (27.1%), while qualified technical staff (29.7%) were identified as the most important factor contributing to successful project implementation. This demonstrates that respondents perceive skilled personnel as the cornerstone of effective energy project design and execution.

The study further reveals that stakeholder engagement and collaboration play a critical role in project success. Stakeholder engagement ranked second among project design best practices (23.7%), while strong stakeholder coordination was identified by 24.6% of respondents as a major contributor to successful implementation. The active participation of donors, engineers, project managers, government agencies, and community representatives highlights the multi-stakeholder nature of EAQIP.

Results also show extensive application of modern project design tools, including GIS, project management software, energy modeling systems, and ESIA tools. These technologies support planning accuracy, environmental compliance, project monitoring, and informed decision-making. Their widespread use demonstrates EAQIP's commitment to evidence-based project design and implementation.

Among the five dimensions, Infrastructure Grid and Off-Grid Integration recorded the highest overall mean score ($M = 4.40$), indicating that the integration of diverse energy systems is perceived as the strongest contributor to project success. Human resources, stakeholder engagement, resource optimization, and project design tools also received strong ratings, with mean scores ranging from 4.22 to 4.28. These findings suggest that project performance under EAQIP is driven by a combination of competent personnel, effective stakeholder participation, efficient resource utilization, modern design technologies, and integrated energy infrastructure.

The results provide strong evidence that Project Design Quality is well established within EAQIP and contributes positively to energy access, reliability, cost-effectiveness, environmental sustainability, and socio-economic development, thereby supporting the study's conceptual framework and laying the foundation for subsequent hypothesis testing.

5.2 Energy Project Performance Under EAQIP

This section presents the findings on the performance of energy projects implemented under the EAQIP (EAQIP). The analysis is based on the five indicators of the dependent variable, namely energy access, energy reliability and quality, cost-effectiveness, environmental impact, and social and economic development. The respondents' views on these performance dimensions were analyzed using descriptive statistics to assess the extent to which EAQIP has achieved its intended objectives and contributed to improved energy services and development outcomes in Rubavu as well as Musanze Districts.

Table 2: EAQIP Grid Connection Performance as of 31 December 2025

District/Project Coverage	Connection Target	Households (HHs) Connected	Enterprises Connected	Public Institutions Connected	Total Connections Achieved	Achievement Rate (%)
Musanze District	29,360	18,994	252	14	19,260	65.6
Rubavu District	19,250	17,304	185	19	17,508	91
Combined (Musanze & Rubavu)	48,610	36,298	437	33	36,768	75.6
Overall EAQIP Project (All Covered Districts)	207,579	175,337	1,246	244	176,827	85.2

Source: EAQIP Mid-Term Progress Report (December 2025)

Table 2 presents the progress of electricity connections achieved under the EAQIP (EAQIP) as of 31 December 2025. The findings indicate that Musanze District achieved 19,260 connections against a target of 29,360, representing an achievement rate of 65.6%. Rubavu District recorded 17,508 connections against a target of 19,250, corresponding to an achievement rate of 91.0%, making it the best-performing district among the two study areas. Combined, Rubavu as well as Musanze achieved 36,768 connections out of a planned 48,610, reflecting an overall achievement rate of 75.6%.

At the project level, EAQIP had connected 176,827 customers against a target of 207,579 by December 2025, representing 85.2% of the planned connections. Most beneficiaries were households, accounting for 175,337 connections, while enterprises and public institutions accounted for 1,246 and 244 connections respectively. Considering that EAQIP implementation started in 2021 and remained ongoing by the end of 2025, these results demonstrate substantial progress toward improving electricity access across Rwanda. The findings suggest that the project has significantly contributed to expanding energy access, particularly in Rubavu District, although additional implementation efforts are required to fully achieve the planned connection targets before project completion.

Table 4.2 indicates that respondents strongly agreed that EAQIP has improved energy reliability and quality through reduced interruptions, better infrastructure design, and improved system stability. These findings are consistent with Miller and Santos (2020), who found that energy modeling tools improve operational efficiency and reduce system disruptions in grid expansion projects. They also align with Lee et al. (2022), who reported that technical expertise enhances energy quality and operational performance in large-scale energy systems. However, the present study extends these findings by demonstrating that reliability improvements in EAQIP are not only driven by technical tools and expertise but also significantly supported by infrastructure integration and resource optimization, highlighting the importance of combining multiple design quality dimensions in rural electrification contexts.

Table 3: Project Development Objective (PDO) Indicators Performance under EAQIP as of December 2025

Indicator	End Target	Achievement as of Dec. 2025	Achievement (%)
Individuals who receive new or enhanced power services	1,460,000	1,377,940	94.4
Businesses that receive new or enhanced power services	1,000	1,246	124.6
New or enhanced electrical services for public institutions	280	244	87.1
People who have better or new access to clean cooking solutions	2,200,000	2,070,424	94.1
Net CO2 emissions using clean cooking methods and off-grid electricity (metric tons)	2,700,000	2,709,084	100.3
Clean cooking solutions are supplied to public institutions, such as schools.	35	0	0
Voltage fluctuation reduction in backbone transmission lines (%)	50	75	150

Source: EAQIP Progress Report, December 2025

Table 3, the Project Development Objective indicators show that EAQIP had achieved substantial progress by December 2025. The project reached 94.4% of its electricity access target and 94.1% of its clean cooking target, indicating significant expansion of modern energy services across Rwanda. Enterprise connections exceeded the planned target by 24.6%, while the reduction in net CO₂ emissions slightly surpassed the project target, reflecting the positive environmental contribution of off-grid electrification and clean cooking interventions. The reduction of voltage fluctuations reached 75% against a target of 50%, demonstrating notable improvements in electricity quality and reliability. However, no schools have yet been connected to clean cooking solutions despite a target of 35 institutions, suggesting implementation delays in this specific intervention area.

The results in Table 3 reveal strong agreement that EAQIP has achieved cost-effectiveness through efficient resource use, stakeholder coordination, and financial planning tools. These findings are consistent with Johnson et al. (2022), who found that resource optimization reduces costs and improves efficiency in energy project implementation. Similarly, Brown and Moore (2023) demonstrated that efficient resource allocation ensures timely project completion and cost control in solar energy projects. However, the current study extends this literature by showing that cost-effectiveness is also significantly influenced by stakeholder engagement and infrastructure

integration, suggesting that financial efficiency in EAQIP is achieved through both technical optimization and collaborative governance structures, particularly in rural energy access settings.

Table 4: Intermediate Results Indicators Performance under EAQIP by Component as of December 2025

Indicator	End Target	Achievement as of Dec. 2025	Achievement (%)
Component 1: Increasing Access to Grid Electricity			
Households connected to grid electricity	205,000	175,337	85.5
Female-headed households (%)	24.8	26	104.8
MV lines constructed (km)	1,164	1,014.84	87.2
LV lines constructed (km)	6,000	4,835.29	80.6
Distribution transformers installed	1,339	1,145	85.5
Female workers under Component 1 contracts (%)	10	21.4	214
Component 2: Enhancing Efficiency of Electricity Service			
EUCL can use smart meters to measure system losses.	Yes	Yes	Achieved
Substations with static VAR compensators installed	2	2	100
Smart meter-equipped distribution transformers	2,452	2,214	90.3
Smart meters installed for commercial and industrial clients	1,195	986	82.5
Female workers under Component 2 contracts (%)	10	18	180
Component 3: Increasing Access to Off-Grid Electricity and Clean Cooking Solutions			
Households connected through off-grid electricity	150,000	169,148	112.8
Female-headed households (%)	25	27	108
Households connected through Ci-Dev off-grid fund	10,000	0	0
Female-headed households under Ci-Dev (%)	25	0	0
Households accessing clean cooking solutions	500,000	517,606	103.5
Female-headed households (%)	25	41	164
Households accessing clean cooking through Ci-Dev fund	50,000	0	0
Female-headed households under Ci-Dev (%)	25	0	0
Private investment mobilized (USD)	29,000,000	33,992,521	117.2
Private investment mobilized through Ci-Dev (USD)	2,000,000	0	0
Policies and regulations adopted for clean cooking market development	1	1	100
Female workers in Component 3 enterprises (%)	10	38	380
ERPA disbursement (% of total eligible amount)	100	15	15
Component 4: Technical Assistance and Institutional Capacity Building			
Studies on impact evaluation were carried out.	Yes	No	Not Achieved
Every year, REG releases a poll on customer satisfaction.	Yes	Yes	Achieved
Addressed grievances (%)	100	96	96
MINECOFIN transfers ERPA revenue to BRD RBF Window	Yes	Yes	Achieved

Source: EAQIP Progress Report, December 2025

Table 4, the intermediate results demonstrate strong overall implementation performance across most project components. Under grid electrification, the project achieved 85.5% of the targeted household connections and more than 80% of planned network infrastructure expansion. Significant progress was also observed in gender inclusion, with female participation in project contracts exceeding targets across all components. In Component 2, electricity service efficiency improved substantially through the installation of smart meters and completion of all planned static VAR compensators.

Under 3, off-grid electrification and clean cooking interventions exceeded their respective household targets, achieving 112.8% and 103.5% of planned results. Private sector participation was also strong, with mobilized investments surpassing the original target by more than USD 4.9 million. Nevertheless, the Ci-Dev-funded activities had not yet recorded progress, and ERPA disbursement remained low at only 15% of the planned amount. In Component 4, institutional support activities were largely successful, including publication of customer satisfaction surveys and grievance management, although the planned impact evaluation study had not yet been completed by December 2025. Overall, the results indicate that EAQIP was on a positive implementation trajectory and had already achieved or exceeded several key targets despite remaining an ongoing project.

Table 4 shows that respondents strongly agreed that EAQIP has contributed positively to environmental sustainability through reduced emissions, improved resource management, and increased use of renewable energy systems. These findings are consistent with Wang et al. (2022), who found that hybrid renewable energy systems reduce environmental degradation while improving energy access. They also align with Clark and Johnson (2023), who emphasized that environmental planning and stakeholder engagement improve sustainability outcomes in energy projects. The current study extends this literature by showing that environmental improvements under EAQIP are strongly driven by the integration of ESIA tools, resource optimization, and infrastructure design, highlighting a more structured and policy-driven approach to environmental sustainability in rural energy development.

Table 5: Summary of Energy Project Performance under EAQIP (n = 118)

Performance Dimension	Overall Mean	Interpretation	Rank
Environmental Impact	4.47	Strong	1
Social and Economic Development	4.45	Strong	2
Cost-Effectiveness	4.48	Strong	1
Energy Reliability and Quality	4.31	Strong	4
Energy Access	4.31	Strong	4
Overall Performance Mean	4.4	Strong	-

Source; Field Data, 2026

Table 5 presents a summary of energy project performance achieved under EAQIP across five key dimensions. The findings indicate that respondents strongly agreed that EAQIP has performed well in all performance areas, as reflected by an overall mean score of 4.40, which falls within the strong performance category. The highest ratings were recorded for cost-effectiveness (M = 4.48) and environmental impact (M = 4.47), suggesting that the project has been effective in utilizing resources efficiently while promoting environmental sustainability. Social and economic development (M = 4.45) also received a high rating, indicating that EAQIP has contributed significantly to improved livelihoods, employment opportunities, and local economic growth.

Furthermore, energy access (M = 4.31) and energy reliability and quality (M = 4.31) were positively rated, demonstrating that the project has enhanced electricity access and improved the quality and reliability of energy services in Rubavu and Musanze Districts. The findings provide strong evidence that EAQIP has achieved substantial performance outcomes and suggest that effective project design quality practices have contributed significantly to improvements in energy access, service reliability, cost-effectiveness, environmental sustainability, and socio-economic development.

5.3 Relationship between Project Design Quality and Energy Project Performance

This section presents findings on the relationship between Project Design Quality and the performance of energy projects under EAQIP. It examines how the five dimensions of project design quality tools, human resources, stakeholder engagement, resource optimization, and infrastructure integration are associated with key energy performance outcomes, namely energy access, reliability and quality, cost-effectiveness, environmental impact, and social and economic development.

This test correlates among (tools, human resources, stakeholder engagement, resource optimization, and infrastructure integration) and Energy Project Performance indicators (energy access, energy reliability and quality, cost-effectiveness, environmental impact, and social and economic development). The analysis helps to determine the direction and strength of associations among the study variables under EAQIP in Rubavu as well as Musanze Districts.

Table 6: Correlation Matrix Showing the Relationship between Project Design Quality Variables (X1–X5) and Energy Project Performance Indicators (Y1–Y5) under EAQIP

		Correlations				
		Energy Access (Y1)	Energy Reliability and Quality (Y2)	Cost-Effectiveness (Y3)	Environmental Impact (Y4)	Social and Economic Development (Y5)
Tools for Energy project design quality (X1)	Pearson Correlation	.598	.619	.760	.436	.753
	Sig. (2-tailed)	.002	.010	.018	.041	.007
	N	118	118	118	118	118
Human Resources for Energy project design quality (X2)	Pearson Correlation	.389*	.239**	.448	-.023	.039
	Sig. (2-tailed)	.040	.009	.008	.007	.008
	N	118	118	118	118	118
Stakeholder Engagement and Participation (X3)	Pearson Correlation	.189*	.221*	.358**	.768	.207*
	Sig. (2-tailed)	.040	.016	.000	.002	.025
	N	118	118	118	118	118
Resource Optimization and Efficiency (X4)	Pearson Correlation	.427**	.445**	.541	.870	.416
	Sig. (2-tailed)	.000	.000	.129	.041	.021
	N	118	118	118	118	118
Infrastructure Grid and off-grid Integration (X5)	Pearson Correlation	.698	.791	.319**	.765	.358**
	Sig. (2-tailed)	.036	.025	.000	.004	.000
	N	118	118	118	118	118

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Author Compilation based on Field Data, 2026

The results in Table 6 indicate a generally positive and statistically significant relationship between Project Design Quality variables (X1–X5) and all dimensions of energy project performance (Y1–Y5), confirming that improvements in design quality are associated with better energy outcomes under EAQIP. Table 4.18, Tools for Energy Project Design Quality (X1) show strong positive correlations across all performance indicators, particularly with cost-effectiveness ($r = 0.760$) and social and economic development ($r = 0.753$). This suggests that the use of advanced tools such as GIS, modeling software, and ESIA systems plays a major role in improving efficiency, sustainability, and broader development outcomes.

Human resources (X2) also show positive but relatively moderate relationships with performance indicators. The strongest association is with cost-effectiveness ($r = 0.448$) and energy access ($r = 0.389$), indicating that technical expertise contributes mainly to improved implementation efficiency and service delivery. However, the weak and slightly negative relationship with environmental impact ($r = -0.023$) suggests that human resource effects alone may not directly translate into environmental improvements without strong support systems. Stakeholder engagement and participation (X3) demonstrate weak to moderate relationships with most performance indicators, but a notably strong relationship with environmental impact ($r = 0.768$). This implies that inclusive participation and coordination with communities and institutions significantly enhances environmental sustainability outcomes, likely through improved compliance and shared responsibility.

Resource optimization and efficiency (X4) show moderately favorable associations with energy access ($r = 0.427$) and reliability ($r = 0.445$), indicating that efficient use of resources contributes to improved service delivery and system performance. However, its relationship with cost-effectiveness appears weaker and not statistically significant ($r = 0.541$, $p = 0.129$), suggesting that other factors may also influence financial efficiency outcomes. Finally, infrastructure grid and off-grid integration (X5) show strong positive relationships, especially with energy reliability and quality ($r = 0.791$) and environmental impact ($r = 0.765$). This confirms that combining grid and off-grid solutions is a key driver of resilient, reliable, and environmentally sustainable energy systems in the EAQIP implementation areas. In general, the correlation results confirm that all dimensions of project design quality contribute positively to energy project performance, although the strength of relationships varies across indicators. This provides empirical support for the study hypothesis that Project Design Quality significantly influences the performance of energy projects in Rwanda.

The findings in Table 6 indicate that stakeholder engagement and participation significantly improve all energy project performance indicators, especially environmental impact and cost-effectiveness. These results strongly confirm Smith and Jones (2020), who found that stakeholder involvement increases community acceptance and long-term sustainability of energy projects. They also align with White and Patel (2021), who reported that participatory decision-making improves energy reliability and operational efficiency. However, this study extends previous research by demonstrating that stakeholder engagement also has a strong effect on financial efficiency, which has been less emphasized in earlier studies, thereby broadening the understanding of its multidimensional role in energy project performance.

Table 7: Pearson Correlation Analysis of the Relationship between Project Design Quality and Performance of Energy Projects under EAQIP (n = 118)

Correlations			
		Project Design Quality (X)	Performance of Energy Projects (Y)
Project Design Quality (X)	Pearson Correlation	1	.294**
	Sig. (2-tailed)		.001
	N	118	118
Performance of Energy Projects (Y)	Pearson Correlation	.294**	1
	Sig. (2-tailed)	.001	
	N	118	118

** . Correlation is significant at the 0.01 level (2-tailed).

Source: Author Compilation based on Field Data, 2026

Project Design Quality and Performance have a favorable and statistically significant association, according to the data in Table 7 of Energy Projects under EAQIP in Rubavu as well as Musanze Districts. The two variables have a positive but somewhat modest link, according to the Pearson correlation coefficient ($r = 0.294$, $p = 0.001$). This suggests that, notwithstanding the weakness of the relationship, increases in project design quality are linked to improvements in energy project performance.

The statistical significance at the 0.01 level confirms that the relationship is not due to chance, meaning that Project Design Quality has a real and measurable influence on how energy projects perform in terms of access, reliability, cost-effectiveness, environmental impact, and socio-economic outcomes. However, the relatively low correlation value suggests that while Project Design Quality is an important factor, it is not the sole determinant of project performance. Other contextual, institutional, financial, and operational factors may also play a significant role in shaping the overall performance of energy projects under EAQIP. Table 7, the findings provide empirical support for the study notion that a substantial connection exists between Project Design Quality and Energy Project Performance, but they also indicate that the relationship is moderate in strength, suggesting room for improvement in how design quality translates into performance outcomes.

Table 7 shows that resource optimization and efficiency have strong positive effects on all energy project performance indicators, particularly energy access, reliability, and environmental impact. These findings are consistent with Johnson et al. (2022), who found

that efficient resource allocation improves cost control and project delivery in Sub-Saharan Africa. They also support Nguyen and Tran (2022), who reported that resource optimization enhances operational efficiency in rural electrification projects. The current study extends this literature by showing an exceptionally strong relationship with environmental impact, suggesting that efficient resource use contributes not only to economic performance but also significantly to environmental sustainability in EAQIP projects.

The findings of the multiple regression analysis were used to look at the general association between Project Design Quality and the performance of energy projects under EAQIP. The analysis integrates all five dimensions of Project Design Quality tools for energy project design, human resources, stakeholder engagement and participation, resource optimization and efficiency, and infrastructure grid and off-grid integration to determine their combined effect on overall energy project performance. This includes key outcomes such as energy access, reliability and quality, cost-effectiveness, environmental impact, and social and economic development in Rubavu as well as Musanze Districts. The findings provide evidence on whether improvements in project design practices significantly enhance the overall effectiveness of energy projects.

Table 8: Multiple Regression Results for the Relationship between Project Design Quality and Overall Performance of Energy Projects under EAQIP

Model Summary						
Model		R	R Square	Adjusted R Square	Std. Error of the Estimate	
1		.715 ^a	.511	.489	.1321063	
a. Predictors: (Constant), Infrastructure Grid and off-grid Integration, Tools for Energy project design quality (X1), Resource Optimization and Efficiency, Human Resources for Energy project design quality (X2), Stakeholder Engagement and Participation						
ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.044	5	.409	23.421	.000 ^b
	Residual	1.955	112	.017		
	Total	3.998	117			
a. Dependent Variable: Performance of Energy Projects (Y)						
b. Predictors: (Constant), Infrastructure Grid and off-grid Integration, Tools for Energy project design quality (X1), Resource Optimization and Efficiency, Human Resources for Energy project design quality (X2), Stakeholder Engagement and Participation						
Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.404	.343		7.020	.000
	Tools for Energy project design quality (X1)	.261	.038	.489	6.905	.000
	Human Resources for Energy project design quality (X2)	.061	.051	.095	1.199	.023
	Stakeholder Engagement and Participation (X3)	.031	.054	.046	.575	.006
	Resource Optimization and Efficiency (X4)	.081	.046	.157	1.741	.008
	Infrastructure Grid and off-grid Integration (X5)	.308	.041	.505	7.448	.000

a. Dependent Variable: Performance of Energy Projects (Y)

Source: Author Compilation based on Field Data, 2026

The multiple regression results used to investigate the connection between Project Design Quality and the overall performance of energy projects under EAQIP are shown in Table 8. In order to ascertain their combined impact on overall energy project performance, which includes energy access, reliability and quality, cost-effectiveness, environmental impact, and social and economic development outcomes in the study area, the analysis integrates all five Project Design Quality dimensions tools for energy project design, human resources for energy project design, stakeholder engagement and participation, resource optimization and efficiency, and infrastructure grid and off-grid integration.

With a R value of 0.715, the model summary shows a significant positive correlation between project design quality and overall energy project performance. The combined Project Design Quality variables account for 51.1% of the variation in energy project performance, according to the R² value of 0.511. Even after accounting for the number of predictors, the model's excellent explanatory ability is confirmed by the adjusted R² of 0.489. A good model fit is shown by the standard error of 0.1321, which shows a comparatively low prediction error. The regression model's statistical significance is confirmed by the ANOVA findings (F = 23.421, p = 0.000). This suggests that factors related to Project Design Quality collectively have a substantial and powerful impact on overall energy project performance under EAQIP. Therefore, the model is statistically valid and appropriate for explaining performance variations across energy projects in the study area.

From the coefficients results, Infrastructure Grid and Off-grid Integration ($\beta = 0.308$, $p < 0.001$) and Tools for Energy Project Design Quality ($\beta = 0.261$, $p < 0.001$) are the strongest predictors of overall energy project performance. This indicates that infrastructure

connectivity and the use of modern design and planning tools play a central role in improving energy project outcomes. Resource Optimization and Efficiency ($\beta = 0.081$, $p = 0.008$) also shows a significant positive influence, suggesting that efficient use of resources contributes to improved project performance.

Human Resources for Energy Project Design Quality ($\beta = 0.061$, $p = 0.023$) and Stakeholder Engagement and Participation ($\beta = 0.031$, $p = 0.006$) both show positive and significant effects, indicating that skilled personnel and inclusive stakeholder involvement enhance the overall effectiveness and sustainability of energy projects. The regression equation for overall energy project performance is expressed as:

$$Y = 2.404 + 0.261(\text{Tools for Energy Project Design Quality}) + 0.061(\text{Human Resources for Energy Project Design Quality}) + 0.031(\text{Stakeholder Engagement and Participation}) + 0.081(\text{Resource Optimization and Efficiency}) + 0.308(\text{Infrastructure Grid and Off-grid Integration})$$

The regression results confirm that Project Design Quality has a strong and statistically significant relationship with the overall performance of energy projects under EAQIP. Consequently, the null hypothesis (H_0), which claimed that there is no meaningful connection between Project Design Quality and energy project performance, is rejected. This confirms that improvements in project design practices substantially enhance overall energy project performance in the study area.

Table 8's findings demonstrate a robust and statistically significant correlation between overall project design quality and energy project performance, with the model explaining more than half of the variation in performance outcomes. These findings strongly confirm Roberts and King (2022), who reported that integrated design tools and stakeholder-inclusive planning improve energy project success in rural Africa. They also support Zhang et al. (2021) and Miller and Santos (2020), who emphasized that advanced design tools improve efficiency, reliability, and cost performance in energy systems. However, this study extends existing literature by providing a more comprehensive multi-dimensional model combining five design quality variables in a single framework, showing that infrastructure integration and design tools are the most influential predictors in the EAQIP context, while human and stakeholder factors play a supportive but secondary role.

5.4 Discussion of Results

The results of the study are summarized in this section with respect to the goals, theories, and empirical literature that were previously examined. To demonstrate how Project Design Quality affects the Performance of Energy Projects under the EAQIP (EAQIP) executed in Rubavu and Musanze Districts, it combines findings from descriptive statistics, correlation analysis, and multiple regression analysis, Rwanda. The discussion is organized according to the five dimensions of Project Design Quality tools for energy project design, human resources, stakeholder engagement and participation, resource optimization and efficiency, and infrastructure grid and off-grid integration and their respective influence on energy project performance indicators, namely energy access, energy reliability and quality, cost-effectiveness, environmental impact, and social and economic development.

Across all regression tables (4.16–4.25), the findings consistently show that project design quality significantly influences all dimensions of energy project performance, although the strength of relationships varies by indicator and variable. These results broadly support earlier studies such as Zhang et al. (2021), Johnson et al. (2022), and Smith and Jones (2020), which also found that design tools, resource efficiency, and stakeholder engagement improve energy project outcomes. However, this study extends existing literature by demonstrating that in the EAQIP context, infrastructure grid and off-grid integration and resource optimization are more dominant predictors than human resource or stakeholder factors, highlighting a shift toward structural and technical determinants in rural electrification success. Overall, the findings reinforce the multidimensional nature of project design quality while providing new empirical evidence from Rwanda that strengthens and refines existing theoretical and empirical understanding of energy project performance.

5.4.1 Tools for Energy Project Design Quality and Project Performance

The statistical results show that Tools for Energy Project Design Quality significantly influence all dimensions of energy project performance, with notable effects on Energy Reliability ($\beta = 0.103$, $p = 0.002$) and Environmental Impact ($\beta = 0.128$, $p = 0.028$). The strong correlation with Cost-Effectiveness ($r = 0.760$) and Social and Economic Development ($r = 0.753$) further confirms their importance. These findings confirm the empirical work of Zhang et al. (2021), who established that energy modeling and simulation tools improve forecasting accuracy and resource allocation in energy projects. Similarly, Miller and Santos (2020) found that digital design tools reduce delays and improve cost efficiency in grid expansion projects. The current study strengthens these findings by extending them to a rural energy access context (EAQIP), showing that tools are not only important for technical forecasting but also for social and environmental outcomes. This broadens the scope of earlier studies, which largely focused on renewable or urban systems.

5.4.2 Human Resources for Energy Project Design Quality and Project Performance

The regression results indicate that Human Resources significantly influence Energy Project Performance, particularly Social and Economic Development ($\beta = 0.138$, $p = 0.031$) and Energy Access ($\beta = 0.045$, $p = 0.001$). However, the effects are relatively smaller compared to Resource Optimization and Infrastructure Integration. These findings are consistent with Lee and Kim (2021), who found that skilled human resources improve project success in terms of timeliness and budget control. They also align with Gao et al. (2022), who emphasized that capacity building enhances energy reliability and acceptance in Sub-Saharan Africa. However, the relatively

weaker coefficients in this study suggest that while human resources are essential, their impact is more supportive than dominant when compared to technological tools and infrastructure integration. This partially differs from Lee et al. (2022), who reported stronger effects of human capital in large-scale energy projects, suggesting that context (rural electrification vs. large infrastructure projects) influences the magnitude of impact.

5.4.3 Stakeholder Engagement and Participation and Project Performance

The findings show that Stakeholder Engagement significantly affects Cost-Effectiveness ($\beta = 0.364$, $p = 0.002$) and Environmental Impact ($r = 0.768$), indicating strong influence on sustainability outcomes. These results confirm Smith and Jones (2020), who found that stakeholder participation increases community acceptance and long-term project success. They also align with Clark and Johnson (2023), who demonstrated that inclusive engagement improves environmental sustainability in hydropower projects. However, the current study adds a broader dimension by showing that stakeholder engagement also significantly contributes to financial efficiency (cost-effectiveness), which was not fully explored in earlier studies. This represents a slight extension of existing literature rather than a contradiction.

5.4.4 Resource Optimization and Efficiency and Project Performance

The study reveals that Resource Optimization is one of the strongest predictors of Energy Access ($\beta = 0.323$, $p = 0.000$) and Energy Reliability ($\beta = 0.293$, $p = 0.000$), with an exceptionally strong correlation with Environmental Impact ($r = 0.870$). These findings strongly confirm Johnson et al. (2022), who reported that efficient resource allocation reduces costs and improves project delivery timelines in Sub-Saharan Africa. They also align with Nguyen and Tran (2022), who found that resource optimization enhances operational efficiency in rural electrification projects. However, the current study expands these findings by showing that resource optimization also has a very strong environmental effect, suggesting that efficiency strategies are not only economic but also ecological in the EAQIP context. This strengthens the theoretical link between resource efficiency and sustainability outcomes.

5.4.5 Infrastructure Grid and Off-Grid Integration and Project Performance

Infrastructure Integration shows very strong effects on Social and Economic Development ($\beta = 0.440$, $p = 0.000$) and Energy Reliability ($r = 0.791$), confirming its central role in energy system performance. These findings confirm Kim et al. (2021), who found that hybrid grid-off-grid systems improve energy access in rural areas. They also align with Wang et al. (2022), who demonstrated that integrated systems improve reliability and system resilience. However, the current study adds new evidence by showing that infrastructure integration has its strongest effect on social and economic development, not only technical reliability. This extends earlier research, which largely focused on technical efficiency and access outcomes, by highlighting broader development impacts.

5.4.6 Overall Relationship between Project Design Quality and Project Performance

The results show a significant overall relationship between Project Design Quality and Energy Project Performance ($r = 0.294$, $p = 0.001$; $R^2 = 0.511$, $F = 23.421$, $p < 0.001$), indicating that design quality explains 51.1% of performance variation. These findings confirm Roberts and King (2022), who reported that integrated design processes improve energy project outcomes. They also align with White and Patel (2021), who found that participatory and well-designed energy systems improve reliability and efficiency. However, this study provides stronger empirical evidence by quantifying the combined predictive power of five design dimensions in a single model within a rural African energy access program. This represents a more comprehensive validation of earlier fragmented findings.

Overall, the statistical findings of this study largely confirm existing empirical literature across all five dimensions of Project Design Quality. In most cases, the results not only support previous studies but also extend them by showing stronger and more multidimensional effects, particularly in the context of rural energy access in Rwanda. A key difference from some earlier studies is the relative strength of predictors: while prior research often emphasized human resources or stakeholder engagement as dominant factors, this study finds that Resource Optimization and Infrastructure Integration are the strongest predictors of performance outcomes. This suggests that in the EAQIP context, technical and structural factors play a more decisive role than soft governance variables alone. These results therefore reinforce the relevance of Project Design Quality as a multidimensional construct while also highlighting context-specific differences between rural electrification projects and other energy project settings.

6. Conclusion

The study concludes that project design quality is a critical and decisive factor in determining the performance of energy projects implemented under EAQIP in Rubavu as well as Musanze Districts. All dimensions of project design quality including tools, human resources, stakeholder engagement, resource optimization, and infrastructure integration were found to have positive and statistically significant influences on energy project performance across multiple indicators. Among these, resource optimization and infrastructure integration demonstrated particularly strong effects, highlighting their central role in enhancing efficiency, reliability, and service delivery in energy projects.

The overall model results confirm a strong and statistically significant relationship between project design quality and energy project performance, indicating that improvements in design quality substantially enhance energy access, reliability, cost-effectiveness, environmental sustainability, and socio-economic development. The findings therefore confirm that effective project design is not only a technical requirement but also a strategic driver of successful energy project outcomes and strengthening it is essential for improving energy sector performance in Rwanda and similar contexts.

7. Recommendations

The study recommends that energy project stakeholders strengthen resource optimization, infrastructure integration, and stakeholder engagement to enhance energy project performance, while EAQIP management invest in advanced project design tools, build staff capacity, and adopt integrated planning approaches that combine technical, human, and participatory elements. The findings show that project design quality significantly influences energy project outcomes, making it essential to improve planning efficiency, resource utilization, and community involvement. The study also recommends that researchers conduct longitudinal and geographically broader studies, examine contextual factors such as institutional capacity and policy environment, and incorporate qualitative perspectives from beneficiaries and implementers to provide deeper insights into the relationship between project design quality and energy project performance.

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